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# Revegetating Processed Oil Shale in the Upper Mountainbrush Zone of Colorado

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RANGE BRANCH
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## RESEARCH SUMMARY

This study was designed to provide information on methods to establish vegetation on processed oil shale disposal areas without using large volumes of water to leach salts from the processed shale. A secondary objective was to evaluate several species of plants for their adaptability to the soil material and climatic conditions at the study site.

The study was conducted in Garfield County, Colo., at an elevation of 8,160 ft (2 487 m). Unleached, TOSCO II processed oil shale was amended in three ways: (1) covered with 6 to 10 inches (15 to 25 cm) of topsoil, (2) covered with 2 to 4 inches (5 to 10 cm) of rock fragments, and (3) incorporated with barley straw to a depth of 6 to 8 inches (15 to 20 cm) at the rate of 2 tons per acre (0.73 metric tons per ha). Container-grown transplants of all species of shrubs and one forb species were planted on each soil material in 1976. In addition to the amended, processed shale treatments, the test plants were also planted on subsoil material, which served as a comparison. The study site was shaped to provide a comparison of north, south, and level exposures.

Six years after planting, overall plant survival was four times greater on topsoil-covered processed oil shale than on straw-amended processed shale, and one and a half times greater on topsoil-covered shale than on rock-mulched processed shale. Survival of test plants was affected only slightly by differences in plot exposure, but when survival and growth rate were considered together, the north-facing plots were shown to be most favorable to plants. Only two plant species, fourwing saltbush and prostrate summer cypress, grew equally well on all soil materials. These two, plus rubber rabbitbrush, mountain big sagebrush, and green ephedra, were the only plant species showing satisfactory adaptability on topsoil-covered processed oil shale.

Precipitation received at the study site has been sufficient to gradually decrease the salinity and sodicity of processed oil shale covered by 6 to 10 inches (15 to 25 cm) of topsoil. Maximum temperatures occurring in the top 1 inch (2.5 cm) of processed oil shale may be inimical to seed germination and seedling survival. Otherwise, the temperature regimes and soil water potentials in processed shale should not preclude the successful establishment of adapted plants on uncovered materials.

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## INTRODUCTION

Oil shales of the Green River Formation of Colorado, Utah, and Wyoming have received appreciable attention as a possible source of fuels and chemicals. The Green River Formation underlies some 34,000 $mi^2$ (700 000 $km^2$), and the deposits of oil shale in this area constitute the largest source of contained shale oil in the world (Sladek 1974).

The properties of processed oil shale depend greatly on the particular technology used in retorting, and to a lesser extent on the shale mineralogy. Unleached processed oil shale resulting from the TOSCO II process of retorting is a difficult medium on which to establish vegetation. Processed shale has a texture similar to silt loam, a moderate water infiltration rate unless compacted excessively, and a pH within the range suitable for growth of most plants (Berg 1973a). However, it has adverse characteristics such as high salinity and alkalinity, low availability of nitrogen and phosphorus, and a questionable availability of potassium (Schmehl and McCaslin 1973). In addition, it is susceptible to wind and water erosion, and tends to coat low-growing vegetation with fine, black dust.

Berg (1973b) found that a variety of plant species can be established in TOSCO II processed oil shale when considerable quantities of water are used to leach out the soluble salts that are harmful to plant growth. In his study, an estimated 47 to 60 inches (118 to 150 cm) of water were applied during 16 months following seeding.

However, circumstances do not always make such a heavy application of water desirable or practical. Therefore, reclamation planners need to determine if there are plant species that could be successfully established on unleached processed oil shale disposal areas, either with or without the addition of amendments or soil cover.

Schaal (1973a) reported that sawdust and peat amendments to processed oil shale produced limited improvement in plant growth in the greenhouse. He also reported (1973b) that leached processed shale provided an excellent medium for plant growth when plots were mulched with peat and sawdust, and fertilizer was applied. In a field experiment with direct seeding, Merkel (1973) observed very little plant survival on unleached processed shale, mixed success on a 50/50 mixture of soil and unleached processed shale, and excellent survival and growth on native topsoil. Merkel also reported some success with several species of shrubs transplanted into a 3- to 8-inch (7.6- to 20-cm) layer of TOSCO II processed shale spread over topsoil. However, his observations were based on only the first 11 months following transplanting.

This paper presents the results of a study begun in 1976 in cooperation with TOSCO (The Oil Shale Company). TOSCO was formerly a partner in the Colony Shale Oil Project located near Parachute, Colo.

Research objectives were (1) to evaluate the effects of three different amendment treatments applied to TOSCO II processed oil shale on the establishment of planted shrubs and forbs, (2) to compare the establishment of the same species of plants when planted on native subsoil material and on amended processed oil shale, (3) to evaluate differences among species of plants used with respect to adaptability to different growing media and topographic exposures, and (4) to compare air and soil temperatures to which plants are exposed when growing in processed oil shale and in soil.

## METHODS

### Study Location

The study site is in Garfield County, Colo., at the head of Davis Gulch, a tributary of Parachute Creek, 14 mi (22.5 km) north-northwest of the town of Parachute (formerly Grand Valley). Elevation of the site is 8,160 ft (2 487 m). The mean annual precipitation for this portion of the Roan Plateau is approximately 20 inches (50.8 cm). Annual snowfall will vary from 80 to 100 inches (203 to 254 cm). Snowpack depths of 6 ft (1.2 m) may be expected. June is the driest month and August (as a result of thunderstorms) usually the wettest. More precipitation is received during January through March than for any month except August. Summer temperature maximum is near 95° F (35° C), and winter minimum is near -20° F (-29° C). Mean annual temperature is approximately 41° F (5° C).

A variety of plant communities exist along the Roan Plateau and its slopes (Ferchau 1973), as can be seen in figure 1. In the immediate vicinity of the study site, the vegetation is dominated by a mixture of shrub species including *Artemisia tridentata* subsp. *vaseyana* (Rydb.), *Artemisia frigida* Wild., *Symphoricarpos oreophilus* A. Gray, *Purshia tridentata* (Pursh) DC, *Amelanchier utahensis* Koehne, *Chrysothamnus nauseosus* (Pall.) Britt. subsp. *salicifolius* (Rydb.) H. and C., and

Figure 1.—Roan Plateau, upper portion of Davis Gulch. Aspen community occupies northfacing slope facing the camera. Mountainbrush community covers south-facing slopes and ridges.

*Chrysothamnus viscidiflorus* (Hook.) Nutt. Common herbaceous plants are *Stipa comata* Trin. & Rupr., *Oryzopsis hymenoides* (R.&S.) Ricker, *Penstemon strictus* Benth., *Eriogonum umbellatum* Torr., and *Machaeranthera bigelovii* A. Gray (Greene). On north-facing slopes, *Populus tremuloides* Michx. forms open to dense stands.

Soils in the vicinity of the study area are Typic Cryoborolls, formed under low temperatures, with a dark surface layer. They are loamy, fine loamy, mixed, and include shallow soils. Local soils are derived from the sandstones, shales, and marls of the Evacuation Creek member of the Green River formation (Fox and others 1973). They are primarily residual, shallow, sandy loams, classified as Lithosols because depth to bedrock averages 9 to 12 inches (23 to 30 cm). The sandstones and shales from which these soils have developed are noncalcareous.

## Plot Design

Prior to this study, Colony Development Operation had opened a small basin, approximately 75 by 120 ft (23 by 37 m), for research that failed to materialize. The company had stockpiled about 400 tons (363 metric tons) of TOSCO II processed oil shale at the site on the south edge of the plateau, overlooking Davis Gulch. The small basin was reshaped so that the long axis (120 ft) ran north and south. The reshaped basin provided three equal-sized sections; a south-facing slope of 25 percent, a level section, and a north-facing slope of 25 percent.

Processed oil shale was spread in a band 33 ft (10 m) wide by 120 ft (37 m) long, to a depth of 2.5 ft (0.76 m). The processed shale was compacted only to the extent achieved by operating a rubber-tired front-end loader in the process of spreading and grading. The graded band of processed oil shale was then treated in three ways: (1) covered with 6 to 10 inches (15 to 25 cm) of topsoil taken from the area adjacent to the basin, (2) mulched with a 2- to 4-inch (5- to 10-cm) layer of broken rock fragments from sandstone bedrock in the basin, and (3) amended with barley straw rototilled into the top 5 to 6 inches (15 to 20 cm) of processed shale at the rate of 2 tons per acre (0.73 metric tons per ha). Each treatment occupied a strip approximately 10 ft (3 m) wide by 120 ft (37 m) long. A similar sized strip of rocky subsoil material, also obtained during reshaping of the basin, was placed adjacent to the three strips of treated processed shale. Figure 2 shows the treatment strips.

Figure 2.—Davis Gulch study site in second growing season. Treatments (left to right): subsoil, straw-amended shale, rock-mulch-covered shale, and topsoil-covered shale.

The four treatments were each divided into 30 plots 10 ft (3 m) long by 4 ft (1.2 m) wide. Within each treatment 10 plots faced south, 10 plots occupied the level bottom of the basin, and 10 plots faced north.

## Planting of Test Species

On June 11, 1976, nine of the 10 plots of each treatment were planted to a single plant species, 10 plants to a plot. Two species were planted on the tenth plot (five of each) due to a shortage of transplants of those particular species. All plants used were container-grown, and were approximately 1 year old. Six of the species were grown at the Forest Service nursery at Coeur d'Alene, Idaho. The remaining five species were grown in the greenhouse at Provo, Utah.

During summer 1976, rodents (attracted to the plots by seed in the barley straw) destroyed some of the test plants. Replantings were made on September 8, 1976, and June 7, 1977, and a rodent-proof fence was put around the plots in September 1976. Table 1 lists the plant species used as well as information available on the original source of each species.

Plants were each given 0.53 gal (2 l) of water at the time of planting, and approximately 0.26 gal (1 l) on June 23 and July 25 of the first growing season.

Table 1.—Plant species used at the Davis Gulch study area, Garfield County, Colo.

| Scientific name | Common name | Accession number | Source |
|---|---|---|---|
| | **Original plantings** | | |
| *Amelanchier utahensis* | Utah serviceberry | U7-67 | Enterprise, Utah |
| *Atriplex canescens* | Fourwing saltbush | — | Bliss, Idaho |
| *Caragana arborescens* | Siberian peashrub | — | Plumfield Nursery, Neb. |
| *Chrysothamnus nauseosus* | Rubber rabbitbrush | — | Sanpete County, Utah |
| *Cercocarpus montanus* | True mountain mahogany | B1-72 | Owyhee County, Idaho |
| *Ephedra viridis* | Green ephedra | U1-73 | Sanpete County, Utah |
| *Hedysarum borealis* | Utah sweetvetch | — | Utah County, Utah |
| *Kochia prostrata* | Prostrate summer cypress | P.I. 356817<br>P.I. 356826 | Kazakh, U.S.S.R. |
| *Lonicera tatarica* | Tatarian honeysuckle | — | Plumfield Nursery, Neb. |
| *Sambucus cerulea* | Blueberry elder | U18-71 | Carbon County, Utah |
| *Symphoricarpos oreophilus* | Snowberry | — | Kaiparowits Plateau, Utah |
| | **Replacement plantings (when different from above)** | | |
| *Artemisia tridentata vaseyana* | Mountain big sagebrush | — | Sanpete County, Utah |
| *Atriplex canescens* | Fourwing saltbush | — | Johnson Canyon, Kane Co., Utah |
| *Kochia prostrata villosissima* | Villous prostrate summer cypress | P.I. 343101 | Kirghizia, U.S.S.R. |
| *Sambucus racemosa* | Red elder | — | Source unknown |

Container-grown plants of mountain big sagebrush were planted on June 8, 1977, as replacements for true mountain mahogany, none of which survived through the first winter.

Data on plant survival and growth (height and mean diameter) were recorded in September and October 1976; May, July, and September 1977; June, July, and September 1978; July and October 1979; August 1980; and August 1981.

## Microclimatic Data and Soil Sampling

A solar-powered, battery-operated data logging system was installed at the Davis Gulch study area in August 1977. Thermistor sensors and thermocouple psychrometers for measuring air and soil temperatures and soil water potentials, respectively, were installed on both north and south slopes (25 percent) on plots located 30 yd (27 m) to the west of the shrub plantings. On each slope a 30- by 30-ft (9-m by 9-m) area was cleared of all vegetation and divided in half. In the center of each half, a 35.3-ft$^3$ (1-m$^3$) block of soil was excavated and replaced with either TOSCO II processed oil shale or local topsoil. Thermistors and thermocouple psychrometers were placed at several depths as the pits were refilled. Processed oil shale or soil was spread over the remainder of the 15- by 15-ft (4.5- by 4.5-m) area to a depth of 4 inches (10 cm). The data logger was programed to record data from all sensors, including a tipping bucket rain-gage, at hourly intervals.

Beginning in the autumn of 1978, processed oil shale and soil cores were obtained with a 3.25-in (8.2-cm) diameter soil auger from each aspect of each treatment on the planted area, for salinity and sodicity analyses.

# RESULTS

## Effect of Treatment and Slope Aspect

Six growing seasons after planting, overall mean survival of plants was highest on subsoil plots (table 2). Mean survival on topsoil-covered processed shale plots was four times greater than on straw-amended processed shale plots, and 50 percent greater than on rock-mulched processed shale plots. Mean height of each species after 6 years is shown in table 3.

Throughout the study, there was little difference in overall plant survival on different exposures. After six seasons, mean survival on the north, level, and south exposures was 41, 38, and 37 percent, respectively. However, the values shown in table 4 help put the overall effect of exposure in perspective. When the number of surviving plants on each exposure is multiplied by the mean height of all plants on that exposure, a success index is obtained for each treatment-exposure combination. As might be expected, the values in table 4 suggest that the north exposure was the most favorable environment for plants in terms of combined survival and growth. Although the overall mean height of surviving plants shown in table 3 would seem to indicate little difference in plant growth on the different soil materials, the similar overall mean height after 6 years is due primarily to the similar growth rate of fourwing saltbush and prostrate summer cypress. Also, the mean height of several other species on the straw-amended and rock-mulched shale plots was increased because of a number of plants that grew within 1 ft (30 cm) of either the topsoil-covered shale or the subsoil plots. Most likely the roots of these latter plants extended into the adjacent topsoil or subsoil.

Table 2.—Percent survival of 11 plant species after six growing seasons, by type of soil material, Davis Gulch, Colo., 1981

| Species | Processed shale | | | Subsoil |
|---|---|---|---|---|
| | Topsoil-covered | Rock-mulched | Straw-amended | |
| Fourwing saltbush | 97 | 94 | 64 | 77 |
| Siberian peashrub | 70 | 80 | 26 | 100 |
| Prostrate summer cypress | 78 | 79 | 33 | 35 |
| Rubber rabbitbrush | 81 | 54 | 11 | 80 |
| Mountain big sagebrush | 31 | 17 | 7 | 57 |
| Tatarian honeysuckle | 80 | 12 | 0 | 85 |
| Green ephedra | 17 | 23 | 0 | 78 |
| Utah sweetvetch | 29 | 9 | 3 | 93 |
| Blueberry and red elder | 69 | 7 | 4 | 41 |
| Utah serviceberry | 20 | 0 | 0 | np* |
| Mountain snowberry | 43 | 20 | 0 | 13 |
| Mean | 56 | 36 | 13 | 66 |

*np = not planted.

Table 3.—Mean height of 11 plant species after six growing seasons, by type of soil material, Davis Gulch, Colo., 1981

| Species | Processed shale | | | Subsoil |
|---|---|---|---|---|
| | Topsoil-covered | Rock-mulched | Straw-amended | |
| | *Inches (cm)* | | | |
| Fourwing saltbush | 54 (137) | 52 (132) | 54 (137) | 55 (140) |
| Siberian peashrub | 18 ( 46) | 9 ( 23) | 6 ( 15) | 34 ( 86) |
| Prostrate summer cypress | 30 ( 76) | 31 ( 79) | 34 ( 86) | 29 ( 74) |
| Rubber rabbitbrush | 18 ( 46) | 14 ( 36) | 22 ( 56) | 29 ( 74) |
| Mountain big sagebrush | 21 ( 53) | 12 ( 30) | 20 ( 51) | 25 ( 64) |
| Tatarian honeysuckle | 16 ( 41) | 14 ( 36) | — | 23 ( 58) |
| Green ephedra | 14 ( 36) | 14 ( 36) | — | 15 ( 38) |
| Utah sweetvetch | 6 ( 15) | 6 ( 15) | 7 ( 18) | 11 ( 28) |
| Blueberry and red elder | 21 ( 53) | 10 ( 25) | 23 ( 58) | 53 (135) |
| Utah serviceberry | 9 ( 23) | — | — | — |
| Mountain snowberry | 11 ( 28) | 10 ( 25) | — | 12 ( 30) |
| Mean | 20 ( 50) | 17 ( 44) | 24 ( 60) | 29 ( 73) |

Table 4.—Index of shrub height × survival by treatment and aspect of exposure, Davis Gulch, Colo.

| Treatment | Plot aspect | | | Total |
|---|---|---|---|---|
| | North | Level | South | |
| Subsoil | [1]1912 | 1777 | 1833 | 5522 |
| Topsoil-covered shale | 1584 | 1300 | 1385 | 4269 |
| Rock-mulched shale | 1012 | 815 | 941 | 2768 |
| Straw-amended shale | 793 | 408 | 892 | 2093 |
| Total | 5301 | 4300 | 5051 | |

[1]Index calculated by multiplying the number of surviving shrubs on each aspect by the mean height of all surviving shrubs on that aspect.

The relatively poor showing of the level exposure in this comparison may have been the result of poor drainage of soil water. The basin used to obtain both north and south exposures resulted in some ponding of surface runoff and snowmelt on portions of the level bottom of the basin.

## Species Adaptability

Tables 2 and 3 show the percent survival and mean height of 11 of the plant species. The 12th species, true mountain mahogany, failed to survive past the first season. If judged by their ability to survive and exhibit at least minimal growth on subsoil, all of the test species except the accession of snowberry from the Kaiparowits Plateau are adapted to the climate of the Roan Plateau. A local ecotype of snowberry may be found that is more adapted to conditions of the study area. Most promising, from the standpoint of both survival and growth after six growing seasons, are fourwing saltbush, prostrate summer cypress, rubber rabbitbrush, mountain big sagebrush, and green ephedra. Although percent survival of sagebrush and ephedra was low on the topsoil-covered shale plots, the surviving plants exhibit good growth and appearance.

Siberian peashrub, elderberry, Tatarian honeysuckle, and Utah sweetvetch cannot be recommended for reclamation use if no more than 6 to 10 inches (15 to 25 cm) of topsoil is used to cover processed oil shale. The first three of these species exhibited good survival on topsoil-covered shale, but growth was poor. Utah sweetvetch might be expected to grow reasonably well if the depth of topsoil were several inches deeper than it was in this study.

Fourwing saltbush and prostrate summer cypress grow as well on topsoil-covered processed shale as on subsoil, which is a good indication of their tolerance of a saline soil material. In fact, these two species exhibited excellent growth on all plots, including the straw-amended shale plots (figs. 2 and 3).

Most of the prostrate summer cypress planted on the study plots were from the original Soil Conservation Service plant introduction numbers 356817 and 356826. However, those used as replacement stock were from SCS P.I. No. 343101 (subsp. *villosissima*). The former two accessions reached somewhat greater size than did the villous subspecies, and may provide greater ground cover and forage.

New plants of both prostrate summer cypress and fourwing saltbush have become established from seed on the plot area. Prostrate summer cypress has also been successful in spreading onto rocky, bare areas adjacent to the study plots, with some new plants growing 20 ft (5 m) away from parent plants. Seedlings of the villous subspecies of prostrate summer cypress appeared to outnumber those of the other two accessions on the straw-amended processed shale plots, perhaps indicating that in the seedling stage the villous variety is more salt tolerant than the other accessions.

Of the five most successful species, only sagebrush and rabbitbrush are native along the upper reaches of the Roan Plateau, where the study was conducted. Local ecotypes of big sagebrush and rubber rabbitbrush may be even more successful than those used in this study, which were from Sanpete County, Utah.

**Figure 3.—Davis Gulch study site, August of sixth growing season. Largest plants are fourwing saltbush, prostrate summer cypress, and blueberry elder.**

Utah sweetvetch, Siberian peashrub, Tatarian honeysuckle, and blueberry elder have all produced seed, but no new plants have resulted to date. Tatarian honeysuckle has suffered some winter dieback. Siberian peashrub was clipped by rabbits on several occasions during winter, which retarded the growth of this species because deep snow nearly always makes the upper portions of plants available to foraging animals. Utah sweetvetch was clipped by rabbits during the summer.

Tatarian honeysuckle, mountain snowberry, Siberian peashrub, and serviceberry all suffered some loss or damage as a result of pocket gophers feeding on the roots.

A number of native plant species have invaded the study plots since they were established in 1976. Thirty-one species were identified on topsoil-covered plots, 22 on subsoil plots, 18 on rock-mulched plots, and 4 on straw-amended plots. Among the invading plant species were four shrubs: *Artemisia frigida* Willd., *A. tridentata* subsp. *vaseyana* (Rydb.), *Chrysothamnus nauseosus* (Pall.) Britt. subsp. *salicifolius* (Rydb.), and *Chrysothamnus viscidiflorus* (Hook.) Nutt. *A. frigida* and *C. viscidiflorus* successfully invaded all treatments except the straw-amended shale. *A. tridentata* has so far been found only on the topsoil-covered shale plots and subsoil plots. *C. nauseosus* has become established on only the topsoil-covered shale plots. The much larger number of native species invading the rock-mulched and topsoiled plots supports the advisability of covering processed oil shale with a layer of soil material.

Many of the herbaceous species invading the topsoiled plots have exhibited excellent vigor and produced abundant seed. Among these are *Oryzopsis hymenoides* (R.&S.) Ricker, *Hordeum jubatum* L., *Phacelia hastata* Doug. ex Lehm., *Penstemon strictus* Benth., *Penstemon*

*pachyphyllus* Gray, *Achillea millefolium* L., *Eriogonum umbellatum* Torr., and *Astragalus spatulatus* Sheld.

Kilkelly and Lindsay (1982) noted that the high boron (B) content of TOSCO II processed oil shale might be inimical to the growth of some plant species. In their studies, they observed sparse vegetative cover on plots of TOSCO II retorted shale without soil cover, and individual plants were stunted in size, with scorched leaves, compared with plants growing on soil control plots. Although we did not determine the B content of any of the plant species growing on our study plots, the possibility exists that B toxicity was a factor in the poor survival of many species, especially on that part of the study area where the processed shale was not covered by topsoil. Conversely, after 6 years the surviving plants of prostrate summer cypress and fourwing saltbush growing on straw-amended processed shale appeared as vigorous as those growing on topsoil-covered processed shale.

## Temperature and Water Potential of Processed Shale

The environment encountered by plants on a processed oil shale disposal area will vary according to the microclimate of each disposal site. Growing conditions will be different at 8,000 ft (2 400 m) in the mountain-brush zone from those at 5,000 ft (1 500 m) in the salt desert shrub zone.

At Davis Gulch, as well as on plots at Sand Wash in Utah, a characteristic of processed oil shale was observed that may explain the differences in temperature measured at various depths in processed shale and in soil. As the warm, dry season of the year begins, moisture stored in processed shale evaporates at an increasing rate. As evaporation proceeds, salts are moved to the surface, and the surface layer of about 1 to 1.5 inches (2.5 to 4 cm) becomes porous, with a thick, often whitish, crust. Unless a hard rain breaks down this porous surface layer it probably acts as a barrier to heat transfer and moisture evaporation. Thus, the temperature regime in processed oil shale at various seasons of the year depends partly on whether or not this porous surface layer is present and how long it persists.

On the south-facing slope at Davis Gulch, temperatures of processed shale and soil at the ¾-inch (2-cm) depth differed between the 2 years in which data were obtained. In 1978 mean temperatures were higher in processed shale than in soil during the first half of June. For the remainder of that summer, mean temperatures were higher in soil than in processed shale (table 5) except on days when rainfall occurred. In 1980, mean temperatures at the ¾-inch depth were higher in processed shale than in soil from the beginning of measurements on April 11 to the last date of observation on October 6 (table 6).

Table 5.—Mean monthly temperatures (°C) of both bare processed oil shale and bare topsoil at five depths on a south exposure with a 25 percent slope, and of the air at a height of 54 inches, Davis Gulch, Colo., 1978

| Measurement | Temperature, °C | | | | | | |
|---|---|---|---|---|---|---|---|
| | June | July | Aug. | Sept. | Oct. | Nov. | Dec. |
| Air 54 inches | 15.7 | 19.4 | 16.6 | 12.1 | 6.8 | -2.0 | -10.9 |
| Topsoil ¾ inch | 19.9 | 24.3 | 21.7 | 16.6 | 10.8 | 1.4 | -3.1 |
| Processed shale ¾ inch | 20.3 | 23.0 | 20.8 | 16.0 | 10.6 | 1.3 | -3.8 |
| Topsoil 4 inches | 17.7 | 22.1 | 20.2 | 16.0 | 10.9 | 1.9 | -2.4 |
| Processed shale 4 inches | 19.0 | 22.4 | 20.5 | 16.2 | 11.3 | 2.2 | -3.4 |
| Topsoil 8 inches | 16.6 | 21.1 | 19.7 | 16.0 | 11.4 | 3.0 | -1.5 |
| Processed shale 8 inches | 18.2 | 22.2 | 21.0 | 16.9 | 12.2 | 3.4 | -2.3 |
| Topsoil 16 inches | 15.1 | 19.7 | 19.1 | 16.0 | 12.0 | 4.5 | -0.2 |
| Processed shale 16 inches | 16.6 | 21.2 | 20.9 | 17.6 | 13.3 | 5.3 | -0.7 |
| Topsoil 32 inches | 12.0 | 16.4 | 17.1 | 15.3 | 12.4 | 6.8 | 2.2 |
| Processed shale 32 inches | 13.1 | 17.7 | 18.8 | 17.0 | 13.8 | 8.1 | 2.3 |

Table 6.—Mean monthly temperatures (°C) of both bare processed oil shale and bare topsoil at five depths on a south exposure with a 25 percent slope, and of the air at a height of 54 inches, Davis Gulch, Colo., 1980

| Measurement | Temperature,°C | | | | | |
|---|---|---|---|---|---|---|
| | Apr.[1] | May | June | July[2] | Aug. | Sept.[3] |
| Air 54 inches | 2.8 | 9.3 | 17.7 | 19.1 | 17.4 | 10.2 |
| Topsoil ¾ inch | 3.8 | 9.2 | 19.4 | 19.9 | 19.1 | 18.1 |
| Processed shale ¾ inch | 3.9 | 10.2 | 22.2 | 24.1 | 21.9 | 18.5 |
| Topsoil 4 inches | 3.3 | 8.8 | 17.6 | 20.0 | 18.7 | 17.4 |
| Processed shale 4 inches | 3.3 | 9.1 | 20.1 | 23.1 | 21.3 | 17.0 |
| Topsoil 8 inches | 2.8 | 8.1 | 15.8 | 19.0 | 18.8 | 16.6 |
| Processed shale 8 inches | 2.8 | 8.2 | 18.7 | 22.2 | 21.0 | 16.9 |
| Topsoil 16 inches | 2.2 | 7.3 | 13.9 | 17.8 | 18.2 | 15.9 |
| Processed shale 16 inches | 2.7 | 7.9 | 16.9 | 21.0 | 20.8 | 17.3 |
| Topsoil 32 inches | 2.3 | 6.2 | 11.0 | 15.1 | 16.3 | 14.8 |
| Processed shale 32 inches | 2.7 | 6.4 | 12.7 | 17.3 | 18.6 | 16.0 |

[1]Data for April 11 through April 30 only.
[2]Data missing for July 17 through July 26.
[3]Data missing for September 6 through September 18.

Mean maximum temperatures at the ¾-inch depth in processed shale were 73° F, 108° F, and 106° F (23° C, 42° C, and 41° C) for the months of May, June, and July 1980, respectively, on the south-facing slope. Corresponding mean maximum temperatures in soil were 61° F, 90° F, and 82° F (16° C, 32° C, and 28° C). On the north-facing slope, mean maximum temperatures for the same months were 63° F, 82° F, and 95° F (17° C, 28° C, and 35° C) in processed shale and 59° F, 82° F, and 84° F (15° C, 28° C, and 29° C) in soil.

Daily maximum temperatures at the ¾-inch depth were mild during May, but in June and July temperatures between 104° F and 122° F (40° C and 50° C) were common. Processed oil shale temperatures near the surface were not lowered as much as soil temperatures by rainfall, although the effects of wetting could depend on whether rains come as showers followed by sunshine the same day, or whether rain is accompanied by overcast skies lasting most, or all, of the day.

Mean temperatures of processed oil shale were nearly always higher than mean temperatures of soil at all depths from 4 to 32 inches (10 to 80 cm) from June through November (tables 5 and 6). From December into March, mean temperatures of processed shale were about 1.8° F (1° C) less than mean temperatures of soil.

On the north aspect plots at Davis Gulch, temperature regimes of processed oil shale and soil were generally related to one another in the same manner as on the south aspect. However, differences between processed shale and soil tended to be less because the effects of incoming solar radiation were moderated by the north-facing plots.

The effect of snow cover in moderating temperature regimes in both processed shale and soil was apparent. As the winter progressed, snow depths became deeper on the north aspect than on the south aspect, and temperatures of both materials decreased faster on the south-facing slope than on the north-facing slope. On the south slope, frost penetration reached the 32-inch (81.3-cm) depth by December 31, and both soil and processed shale were still frozen at this depth on March 15. On the north slope, frost reached the 32-inch depth only in the processed shale by December 31, and then for only 3 days.

Air temperatures 2 inches (5 cm) above the surface were occasionally higher over processed shale than over soil on both south and north aspects, but seldom by more than 3.6° F (2° C).

The assessment of the relative soil water potential regimes in the bare processed oil shale and bare soil was hampered by our being unable to visit the study plots frequently. From June 15 through October 31, 1978, psychrometer readings were taken on eight occasions. For the eight readings, soil water potential on the south-facing soil plot averaged -13, -6, and -11 bars at the 8-, 12-, and 20-inch (20.3-, 30.5-, and 50.8-cm) depths, respectively. Soil water potential on the south-facing processed shale plot averaged -19, -9, and -10 bars at the same

depths. On the north-facing soil plots, average soil water potential for the eight readings was -15, -15, and -10 bars at the 8-, 12-, and 20-inch depths, respectively. On north-facing processed shale plots, comparable averages were -15, -12, and -12 bars. Thus, on southerly slopes the soil water potential in the top 1 ft (30 cm) of processed oil shale may usually be slightly lower than that in soil during much of the growing season. On northerly slopes there may be little difference between processed shale and soil with respect to water potential.

Conversely, the limited number of readings taken during the summers of 1979 and 1980 indicated that processed oil shale may, at times, exhibit higher soil water potentials than soil, on both north and south slopes.

## Salinity of the Growing Medium

Topsoil and processed oil shale samples collected in the third through sixth growing seasons indicate that salinity and sodicity of both materials had decreased on topsoil-covered plots (table 7). The amount of salts in the soil material profile may vary with the season of the year; decreasing during periods of increasing soil moisture, and increasing again as the soil profile dries and capillary action brings dissolved salts upward in the profile. In this study, samples were taken in late summer or early autumn and should be representative of near maximum values of salinity and sodicity for each year.

Sufficient precipitation fell at the study site to prevent any increase in soil salinity by capillary rise of soil water with the passage of time. Although no adequate record of precipitation amounts was obtained, annual precipitation at the four nearest official weather stations was relatively normal for the 1976 through 1981 period except for being lower than normal in 1977 and higher than normal in 1981. Precipitation along the crest of the Roan Plateau should be about 20 inches (50.8 cm) annually, with at least half the total received during the snow-free period. The apparent gradual decrease in sodicity will be beneficial to plants established on soil-covered processed oil shale.

The electrical conductivity and sodium adsorption ratio of processed shale beneath a 2- to 4-inch (5- to 10-cm) layer of slowly decomposing rock mulch remained essentially the same through the first five growing seasons, but decreased sharply in 1981, due possibly to the much greater than normal rainfall received during summer 1981. The electrical conductivity of processed shale that was amended with straw decreased throughout the study period, whereas the sodium adsorption ratio changed little until the sixth year (1981) when it showed a large decrease.

# CONCLUSIONS

We drew the following principal conclusions from our study:

1. Fourwing saltbush and prostrate summer cypress flourished under all treatments, and can be unequivocally recommended for use in the reclamation of processed oil shale disposal areas.

2. Covering unleached TOSCO II processed oil shale with 8 to 10 inches (20 to 25 cm) of topsoil resulted in reasonably good initial establishment of 11 of the 12 plant species tested. However, when survival and rate of growth is considered, only five of the 12 species can be recommended for use on the crest of the Roan Plateau: fourwing saltbush, prostrate summer cypress, rubber rabbitbrush, mountain big sagebrush, and green ephedra. Other tested species showed lower survival and growth rate after 6 years when grown on processed oil shale covered with 6 to 10 inches (15 to 25 cm) of topsoil.

3. Although both the villous and nonvillous forms of prostrate summer cypress established and grew well in the environment encountered in this study, the villous (grey) form was more aggressive in terms of reproduction, especially on the most saline areas.

4. The successful invasion by a number of native perennial species of grasses and forbs on topsoil-covered, unleached, processed oil shale indicates that 8 to 10 inches (20 to 25 cm) of topsoil covering may be adequate for herbaceous species having shallower root systems than most shrubs. Therefore, at least 1 ft (30 cm) of topsoil covering is recommended for herbaceous species.

5. The amount of precipitation received along the crest of the Roan Plateau of western Colorado appears sufficient to prevent salts in unleached, processed oil shale from migrating upward into a topsoil covering. Rather, a gradual decrease in salinity and sodicity of processed oil shale covered by topsoil may be expected.

Table 7.—Change in sodium adsorption ratio (SAR) and electrical conductivity ($EC_e$, mmhos/cm) of the saturation extract of soil materials on the Davis Gulch study plots

| Soil materials | Third season | | Fourth season | | Fifth season | | Sixth season | |
|---|---|---|---|---|---|---|---|---|
| | SAR | $EC_e$ | SAR | $EC_e$ | SAR | $EC_e$ | SAR | $EC_e$ |
| Topsoil (above shale) | 1.5 | 1.8 | 0.6 | 1.3 | 0.4 | 0.6 | 0.7 | 0.5 |
| Shale (beneath topsoil) | 2.7 | 8.2 | .8 | 8.5 | .9 | 3.1 | .6 | 3.3 |
| Rock-mulched shale | 12.7 | 23.0 | 11.0 | 27.0 | 17.0 | 25.0 | 6.2 | 7.8 |
| Straw-amended shale | 16.6 | 31.0 | 11.0 | 22.0 | 16.0 | 18.0 | 2.8 | 5.7 |

No evidence was indicated of a need for a capillary barrier between processed oil shale and a topsoil covering as advocated by Redente and Cook (1981) for sites at lower elevations in the Piceance Basin.

6. Maximum temperatures in the surface 1 inch (2.5 cm) of unshaded, processed oil shale are significantly higher than maximum temperatures in unshaded topsoil on south-facing slopes. During June and July, maximum temperatures of 104° F to 122° F (40° C to 50° C) in processed shale on south slopes could inhibit or prevent germination of seed of some plant species, and might also be lethal to very young seedlings. At depths below the surface inch, the temperature regime in processed shale was not sufficiently different from that in topsoil to adversely affect plant growth.

7. On the south-facing slope, soil water potentials were only slightly lower in the upper 1 ft (30 cm) of unleached, TOSCO II, processed oil shale than in the upper foot of topsoil. On the north-facing slope, soil water potentials during the growing season were very similar in processed shale and topsoil.

## RECOMMENDATIONS

1. Cover processed oil shale with a minimum of 8 inches (20 cm), and preferably 1 ft (30 cm), of topsoil prior to attempting revegetation. If this can be done, it should not be necessary to leach the processed oil shale following its placement at the disposal site.

2. The use of a capillary barrier between Tosco II processed oil shale and a soil covering is not deemed necessary at disposal sites along the crest of the Roan Plateau.

3. For rapid soil protection, utilize fourwing saltbush and prostrate summer cypress, even though they are not native plant species on the upper Roan Plateau.

4. Include local ecotypes of rubber rabbitbrush and big sagebrush in any revegetation program for processed oil shale disposal areas where a minimum of 8 inches (20 cm) of topsoil can be placed over the processed shale. Also give serious consideration to using the nearest source of green ephedra on topsoiled processed shale, especially if the revegetation is planned for elevations between 6,000 and 7,000 ft (1 830 and 2 140 m).

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Ferguson, Robert B.; Frischknecht, Neil C. Revegetating processed oil shale in the upper mountainbrush zone of Colorado. Res. Pap. INT-321. Ogden, Utah: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1983. 9 p.

TOSCO II processed oil shale was covered with topsoil or rock mulch, or amended with straw. Establishment and growth of planted, container-grown shrubs, and changes in salinity of processed shale and soil were monitored for 6 years. Temperatures in processed oil shale and soil are compared.

KEYWORDS: processed oil shale, revegetation, topsoiling, species adaptability, Colorado, capillary barrier, soil temperature, soil amendment, *Kochia prostrata, Atriplex canescens*

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